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Integration of Remote Sensing and GIS Technologies for Blue Carbon Ecosystem Monitoring in Lakkang Island, Makassar City

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Abstract

The blue carbon ecosystem plays a vital role in maintaining the quality of the environment. A monitoring process is needed to provide direction for decision-making related to its management planning. Remote sensing technologies integrated with Geographic Information Systems (GIS) are monitoring methods that can be carried out more quickly, efficiently and accurately. Lakkang Island in Makassar City has a blue carbon ecosystem in the form of mangroves that are vital in absorbing carbon emissions. This research aimed to integrate remote sensing and GIS technologies in monitoring blue carbon ecosystems. Monitoring processes focused on the distribution and extensions of the blue carbon ecosystem, which is carried out through a random forest algorithm. Monitoring the physical condition, like density levels of the blue carbon ecosystem, is carried through the NDVI analysis. The results showed that the distribution of the blue carbon ecosystem on Lakkang Island tends to follow the main flow of the Tallo River, with an area of 58.29 hectares. The blue carbon ecosystem's physical conditions are dominated by dense mangroves that reach 46% of the total area of the ecosystem.

Keywords: Blue Carbon, Ecosystem Monitoring, Lakkang

INTRODUCTION

Blue carbon ecosystems can absorb excessive atmospheric carbon emissions, including mangrove ecosystems, seagrass ecosystems, or peat ecosystems (Lovelock et al., 2019; Tanner & Strong, 2023). The existence of blue carbon ecosystems can reduce carbon emissions in the atmosphere by accumulating them in the surrounding soil or sediment substrate (Alongi, 2022; Jayaraju et al., 2023). Blue carbon is organic carbon sequestered by vegetation such as mangroves, seagrasses, and other vegetation in peatlands or wetlands (Vanderklift et al., 2019). Blue carbon ecosystems can absorb carbon emissions 4 to 5 times more than other ecosystems (Ketaren, 2023). If these ecosystems are degraded or disappear, the stored carbon will be released back into the atmosphere (Hilmi et al., 2021). Therefore, the existence of blue carbon ecosystems has excellent potential to play a role in mitigating climate change and restoring damaged environments (Zeng et al., 2021).

Blue carbon ecosystems also have many other ecological functions besides absorbing carbon emissions in the atmosphere. One example is the mangrove ecosystem, which has so many environmental functions apart from absorbing carbon emissions. Mangrove ecosystems, as blue carbon ecosystems, also have ecological functions such as protecting coastal areas from abrasion and tidal flooding phenomena; nurseries for fish and other brackish water species can also maintain water clarity (Arfan et al., 2022; Sidik et al., 2023). This can be a reason why blue carbon ecosystems, such as mangroves, are vital in environmental sustainability.

Therefore, sustainable management is needed to preserve the blue carbon ecosystem. Sustainable ecosystem management relies heavily on handling or controlling the natural resources in a better and more effective way, so the results of its implementation can benefit society (Pandey

& Sharma, 2021). This form of management has included activities in the form of planning, organising, and controlling together through proper monitoring. Monitoring processes of the blue carbon ecosystems can identify the progress or quality of natural resources in that ecosystem over some time and maintain role to its sustainability (Roy et al., 2019). Monitoring an ecosystem, which is specifically related to its management, can be done based on a collection of information obtained from earth observation data about its condition spatially, spectrally and temporally (Dharmawan et al., 2020; Pandey & Sharma, 2021).

In particular, monitoring one of the blue carbon ecosystems, which is mangroves, was necessary, considering that mangroves are very dynamic ecosystems and can change according to the surrounding environmental conditions. Damage in the mangrove ecosystem can also indicate damage to the other kinds of blue carbon ecosystems (Hariyanto et al., 2023). One of the ways to monitor blue carbon ecosystems is through spatial and spectral monitoring, remote sensing, and the utilisation of Geographic Information Systems (GIS) technology.

Lakkang Island, located in Makassar City, is located between the Tallo and Pampang Rivers in the downstream area, formed due to the sedimentation process between the Tallo and Pampang Rivers. Lakkang Island has unspoiled environmental conditions, thus giving it enormous natural resource potential (Aisyah et al., 2022). One of the potential natural resources on Lakkang Island is the potential for blue carbon ecosystems, that is, mangroves, as revealed (Amal et al., 2020). In addition, Lakkang Island is a waterfront area where almost the entire land is surrounded by rivers to form an island (Ayu et al., 2022). Access to this island is quite tricky because it can only be reached through waterways, namely by crossing the Tallo River, and islands in general form in the middle of the ocean.

Utilising remote sensing and GIS technologies is the right solution to be applied in monitoring the blue carbon ecosystem on Lakkang Island, Makassar City. This method is a more straightforward process and only takes a short time to be able to produce data in the form of the required spatial data. Therefore, integrating remote sensing and GIS technologies can effectively monitor ecosystems in areas that are difficult to access, such as Lakkang Island in Makassar City (Faizal et al., 2023).

RESEARCH METHODS

This research was conducted on Lakkang Island, administratively located in Lakkang Village, Tallo Subdistrict, Makassar City, South Sulawesi Province, as shown in Figure 1. This research combined remote sensing and Geographic Information Systems (GIS) technologies. The object of this research is the blue carbon ecosystem, in this case, the mangrove ecosystem, with a research focus on monitoring the distribution and extent of the blue carbon ecosystem, as well as the physical condition of the blue carbon ecosystem by its density levels. Data collection in the research was carried out through documentation. Remote sensing data used in this research is Sentinel 2A satellite images acquired from the Copernicus database (https://scihub.copernicus.eu/). This research was processed on the Google Earth Engine (GEE) platform and ArcGIS 10.8 software. In general, the data analysis technique in this research was carried out using quantitative descriptive methods. It was carried out in monitoring stages on blue carbon ecosystem distribution and its extent. At the stage of monitoring physical conditions, that is density level of the blue carbon ecosystem.

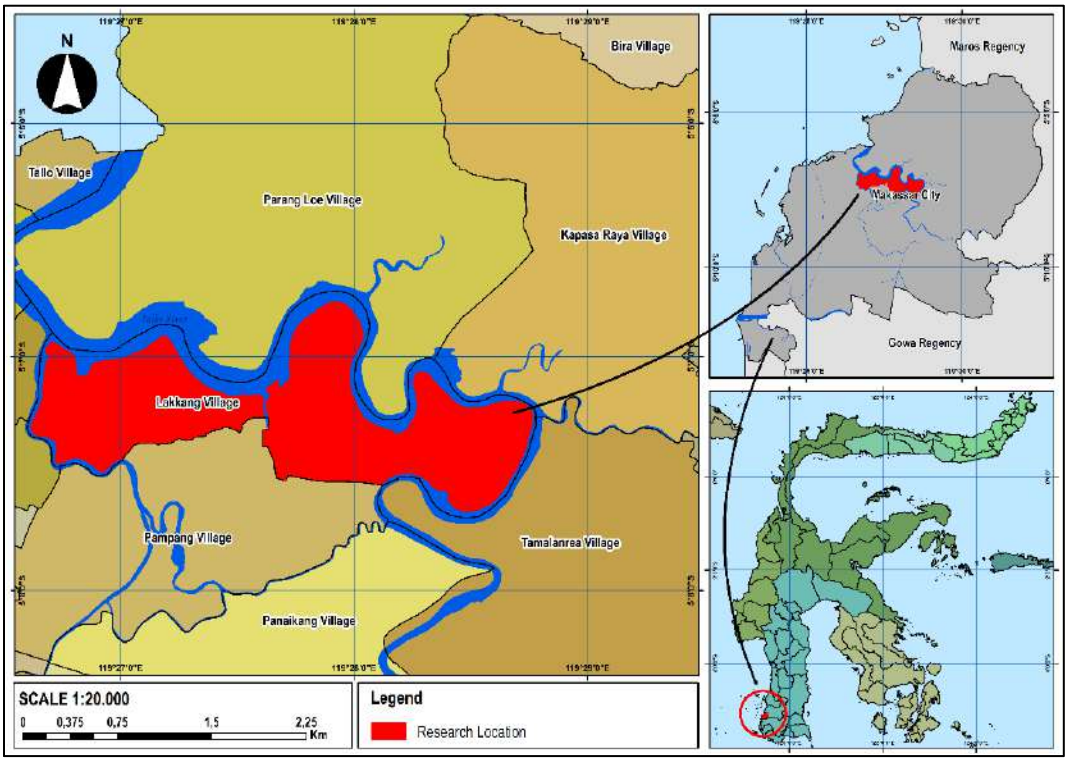

Figure 1. Research Location Maps

Extentions and Distribution Monitoring of Blue Carbon Ecosystem (Mangroves)

Monitoring the distribution and extent of blue carbon ecosystems is carried out through the interpretation of Sentinel 2A satellite images acquired in July 2023. Analysis of the distribution of blue carbon ecosystems, which in this case is the mangrove ecosystem, is done by identifying objects through the spectral values of these objects, that is the mangrove ecosystems. The first thing to do is to choose a spectral channel that is believed to have a better ability to identify. This stage is often referred to as the *preprocessing* stage. The spectral *bands* include B4 (Red), and B8 (Near Infrared/NIR), each of which has a spatial resolution of 10 meters. Because the blue carbon ecosystem, namely mangroves, is always associated with water bodies, B11 (Short-Wave Infrared/SWIR) was also selected in the classification to facilitate the separation of objects from waterbodies (Cisell et al., 2021). After the band selection, object classification is then carried out using the supervised classification method, through the random forest algorithm.

Classification of blue carbon ecosystems using the random forest algorithm relies on the similarity of pixel values of each identified object and its determination through regression trees (Asy'ari et al., 2022). Therefore, the classification of objects through the random forest algorithm then consists of two classes, that is mangrove and non-mangrove to be able to analyze the distribution of blue carbon ecosystems.

Satellite image data processing is fully carried out on the Google Earth Engine platform to get faster and lighter data processing than remote sensing data processing in general (Prasetyo et al., 2021). After the object classification is carried out, the accuracy test is then carried out based on the calculation of Overall Accuracy (OA) through Confusion Matrix, as well as Kappa Statistics (K). The minimum accuracy level that must be achieved based on the calculation of OA through Confusion Matrix is 85% to state that the interpretation is accurate. As for the level

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of accuracy based on Kappa (K) statistics, it is adjusted based on the following interpretation classes as quoted from Asy'ari et al. (2022).

Table 1. Interpretation Class That Based on Kappa *(K)* Coefficient

Kappa coefficient (*K*)	Interpretation
0	Bad
0.10 - 0.20	Less
0.21 - 0.40	Simply
0.41 - 0.60	Medium
0.61 - 0.80	Substantial
0.81 - 0.99	Almost Perfect
1	Perfect

(Source: Asy'ari et. al., 2022)

After the accuracy test is carried out, the interpretation results are then processed using ArcGIS 10.8 software to then calculate the area of the blue carbon ecosystem, namely mangroves as a result of remote sensing data interpretation. The area calculation is carried out using the attribute tool, namely calculate geometry which will then automatically calculate the area of the blue carbon ecosystem that has been interpreted previously.

Physical Conditions Monitoring of Blue Carbon Ecosystem (Mangrove)

Monitoring the physical condition of blue carbon ecosystems is carried out through the analysis of Sentinel 2A satellite images acquired in 2023, which in this case is in the form of analyzing the density level of blue carbon ecosystems, namely mangroves. The analysis was carried out using the NDVI (Normalized Difference Vegetation Index) method, which is a method of analyzing the level of vegetation density that is generally carried out through remote sensing. NDVI analysis is based on observations of the ability of vegetation surfaces to reflect different types of light waves from different satellites, so it is very often used in analyzing the physical condition of a vegetation such as its density level (Dharmawan et al., 2020). After calculating the NDVI value, the next classification of the density level of the *blue carbon* mangrove ecosystem is carried out, based on the classification by the Ministry of Forestry of the Republic of Indonesia (2005) as cited in (Arfan et al., 2023) which is as follows:

Table 2. Classification of Mangrove Density Levels Based on NDVI Values

NDVI Values	Mangrove Density Classification
-1 ≤ NDVI ≤ 0,32	Sparse Mangroves
0,33 ≤ NDVI ≤ 0,42	Medium Mangroves
0,43 ≤ NDVI ≤ 1	Dense Mangroves

(Source: Ministry of Forestry of the Republic of Indonesia, 2005 in Arfan et al., 2023)

RESULTS AND DISCUSSION

Distribution and Extent of Blue Carbon Ecosystem in Lakkang Island, Makassar City

The composite results of the Sentinel 2A image can be seen in Figure 2 below, where on the left side, the blue carbon ecosystem (mangroves) can be clearly seen with a reddish-yellow colour. This is different from vegetation cover in general, which tends to be orange when using the same band composite. In addition, land cover in the form of mangroves also appears to contrast with other land cover such as water bodies and ponds that are black, yellowish green agricultural land, and greyish white built-up land. Then in Figure 2 on the right side, is the result of classification based on a random forest algorithm, which classifies into 3 (three) objects, including mangrove, non-mangrove, and waterbodies/ponds.

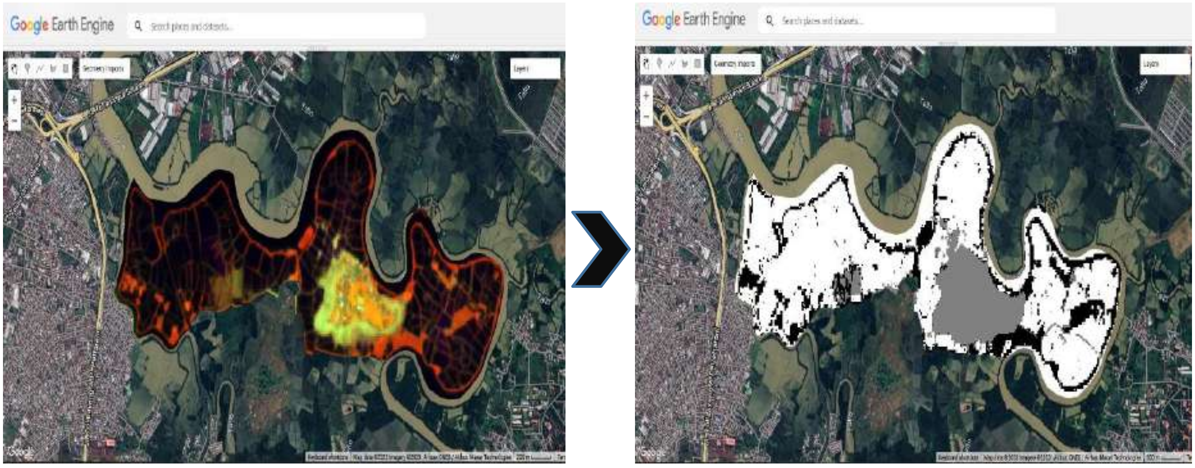

Figure 2. Classification Results Based on Random Forest Algorithm Sentinel 2A Image

The results of object classification in the form of raster data are then processed again through a geographic information system. This is done to be able to know the spatial distribution of blue carbon ecosystems, as well as to know the extent of the blue carbon ecosystem in the form of mangroves on Lakkang Island, Makassar City. The area can be known if the data in raster form is processed into data in vector form, which can only be done using Geographic Information System (GIS) applications. This process also produces a distribution map of blue carbon ecosystems on Lakkang Island, Makassar City as shown in Figure 3 below.

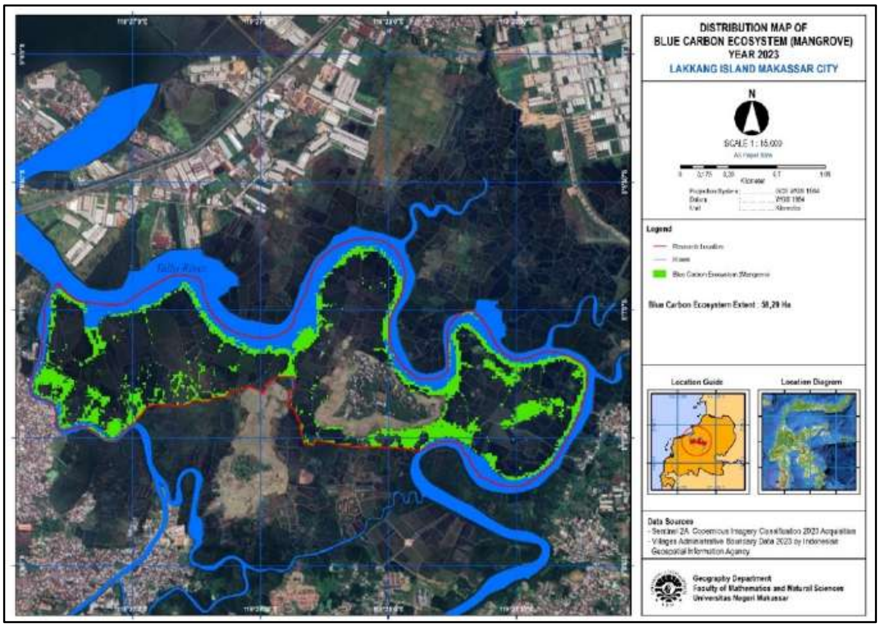

Figure 3. Distribution Map of Blue Carbon Ecosystem (Mangrove) in Lakkang Island

The distribution of blue carbon ecosystems (mangroves) that found on Lakkang Island, Makassar City, is seen to surround the entire island area drained by river water. The distribution looks dominant along the main flow of the Tallo River, which follows the direction of the river flow. As for the area of each classified land cover, along with a graph of the percentage of the area of each land cover class is in Table 3 and Figure 4 as follows :

Table 3. Land Cover Extentions from Classification Results

Land Cover Classification	**Area (Ha)**
Mangroves (*Blue Carbon Ecosystem*)	58,29
Non-Mangrove (Built-up Land, Farmland, Open Land, Scrub)	46,25
Water Body/Pond	237,4
Total	341,94

(Source: Analysis Results, 2023)

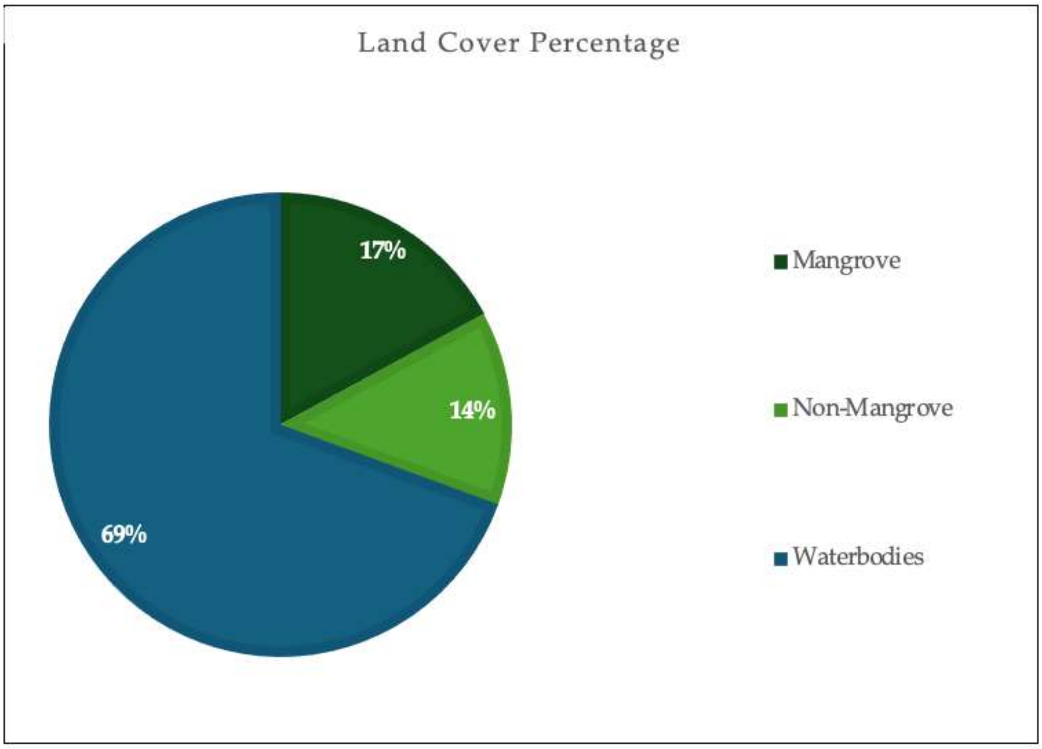

Figure 4. Land Cover Percentage

Land cover in the form of mangroves which is a blue carbon ecosystem on Lakkang Island, Makassar City reaches 17% of the total area. While land cover in the form of water bodies and ponds is the largest by reaching 69% of the total area, and non-mangrove land cover which includes agricultural land, developed land, open land, and shrubs only reaches 14% of the total area. After that, the accuracy of the object classification results was tested, based on the confusion matrix and Kappa (*K*) statistics. The results of this classification accuracy test can be seen in Table 4 as follows :

Table 4. Accuracy Test Results

		Field Results			Number of Rows
		Mangrove	Non-Mangrove	Waterbodies	
Classification Results	Mangrove	40	1	7	57
	Non Mangrove	0	27	1	28
	Waterbodies	5	2	212	219
Number of Columns		45	30	220	
Overall Accuracy		94%			
Kappa (*K*) Statistics		0,87 (Almost Perfect)			

(Source: Analysis Results, 2023)

The results of the accuracy test conducted using the confusion matrix show that the overall accuracy level reaches 94% which exceeds the minimum limit of 85% to state that the classification results are correct. As for the accuracy test results based on Kappa (K) statistics, it shows a number 0.87 which is included in the "almost perfect" interpretation category, based on the interpretation class quoted from (Asy'ari et al., 2022).

Physical Condition of *Blue Carbon* Ecosystem (Density Level) in Lakkang Island, Makassar City

The results of the NDVI analysis of the Sentinel 2A image in the Lakkang Island area of Makassar City can be seen in Figure 5, where green objects are vegetation cover. The results of this analysis have a certain spectral value range, which is used as a reference in determining the physical condition of the vegetation in the form of its density level.

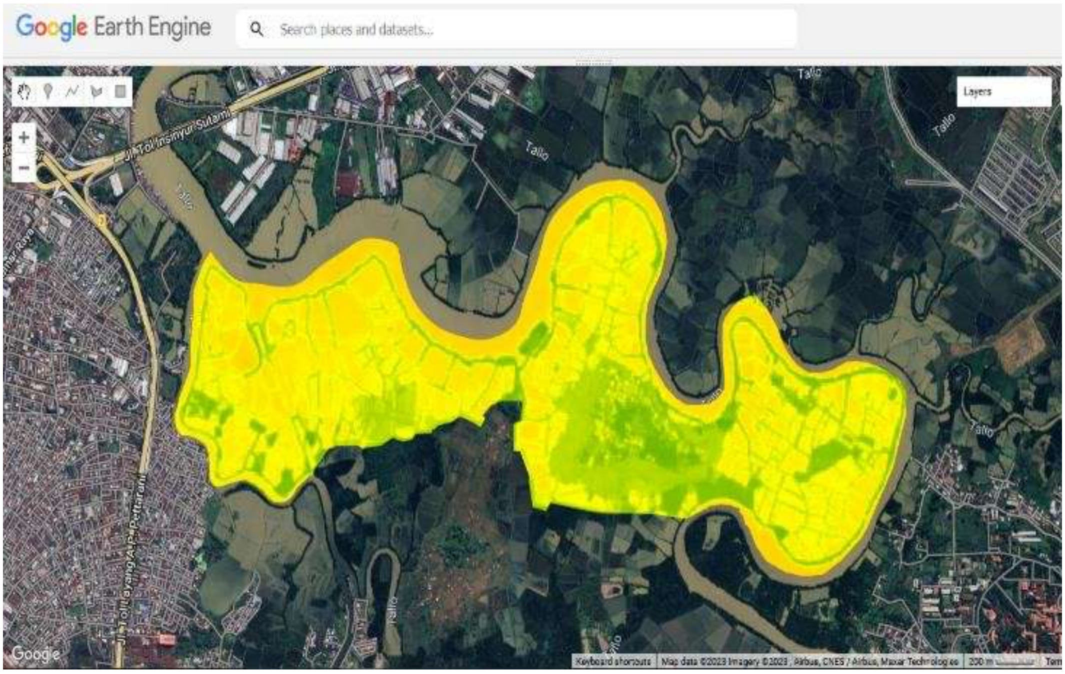

Figure 5. Classification Results Based on Random Forest Algorithm Sentinel 2A Imagery

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For further data processing through Geographic Information System (GIS) applications, which then produces a map of the density level of the blue carbon ecosystem (mangrove) as shown in Figure 6 as follows :

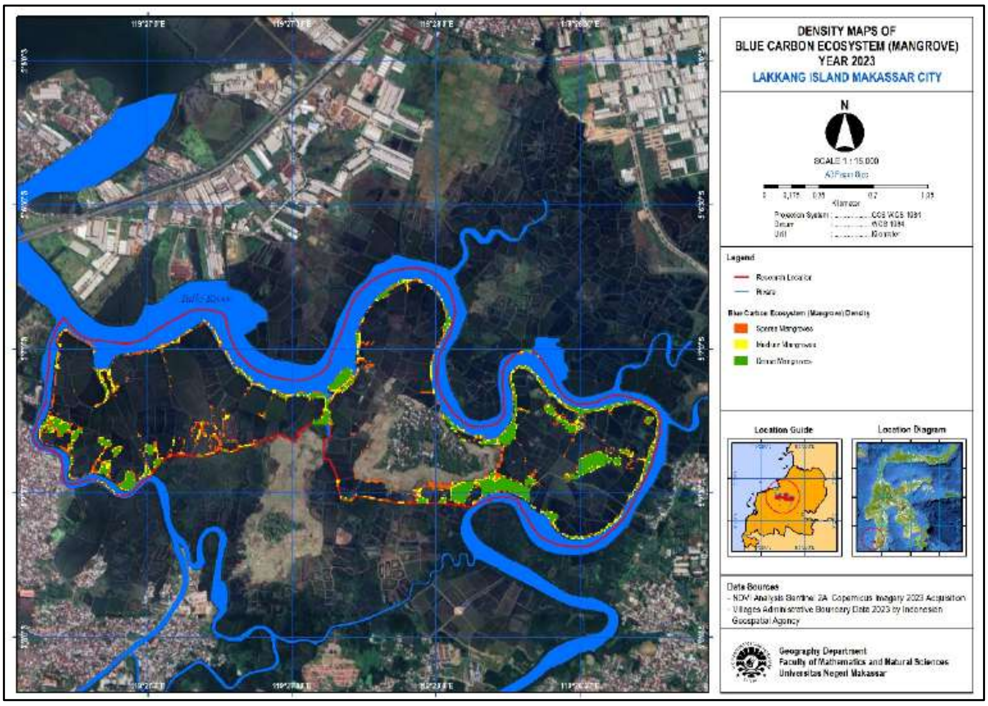

Figure 6. Distribution Map of Blue Carbon Ecosystem (Mangrove) in Lakkang Island

The map shows the physical condition in the form of the density level of the blue carbon ecosystem (mangroves) on Lakkang Island, Makassar City. Based on the results of NDVI analysis of Sentinel 2A images. The results show that the physical condition in the form of the density level of the blue carbon mangrove ecosystem on Lakkang Island, Makassar City consists of dense mangroves, medium mangroves, and sparse mangroves. The data for the ecosystem area based on the density level, along with the percentage is contained in Table 5 and Figure 7 follows:

Table 5. Mangrove Extent Based on Density Level

Density Level	Area (Ha)
Sparse Mangroves	17,77
Medium Mangroves	13,91
Dense Mangroves	26,61
Total	58,29

(Source: Analysis Results, 2023)

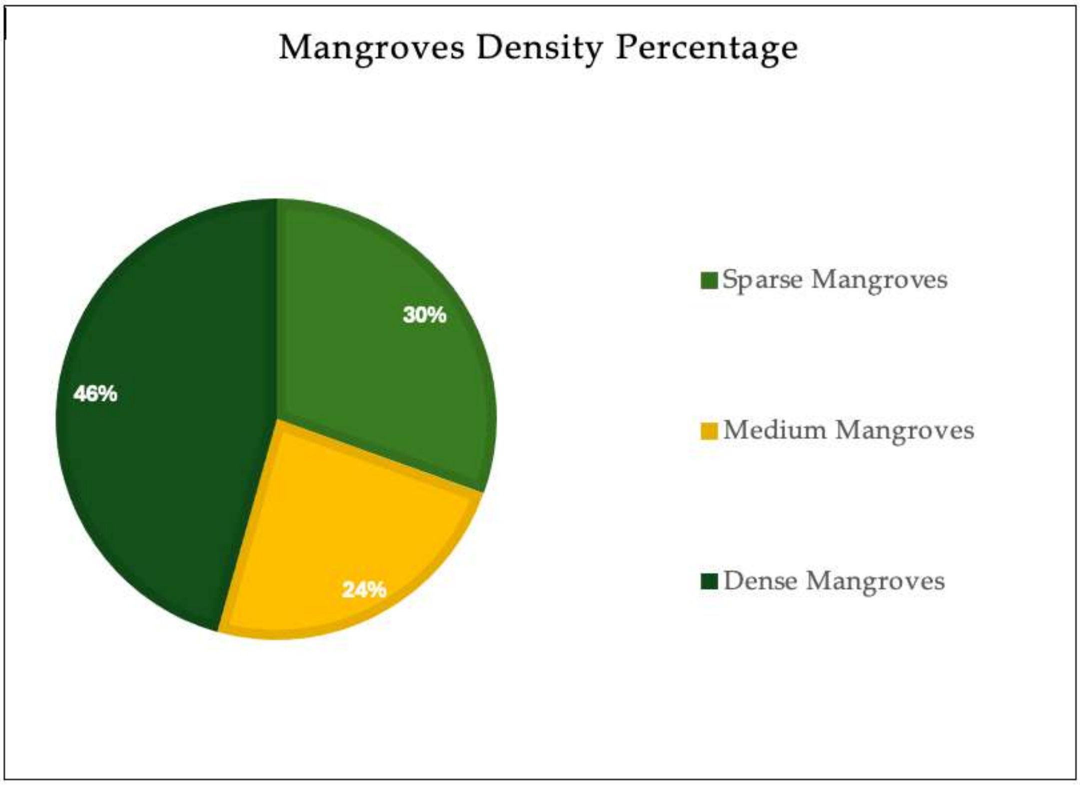

Figure 7. Land Cover Percentage

These data shown the physical conditions in form of blue carbon ecosystem (mangrove) density on Lakkang Island, Makassar City mostly consists of dense mangroves which reach 46% of the total area of the blue carbon mangrove ecosystem. As for the condition of moderate mangroves reaching 24% of the total area of the blue carbon mangrove ecosystem, while for the condition of sparse mangroves reaching 30% of the total area of the blue carbon mangrove ecosystem based on the results of NDVI analysis.

The integration of remote sensing and GIS technologies can produce a form of monitoring of the blue carbon ecosystem on Lakkang Island, Makassar City, which is an area with limited access. Monitoring is carried out to determine the distribution and extent of the blue carbon ecosystem, as well as the physical condition of the blue carbon ecosystem in the form of its density level. The results of distributions monitoring of the blue carbon ecosystem show that the ecosystem that is mangroves is distributed in almost around all parts of Lakkang Island. However, the distribution of blue carbon ecosystems is dominantly located along the main flow of the Tallo River which is located on the banks of the river, starting from the southeast of the island and following the direction of the river flow.

The results of monitoring the area then showed that the area of the blue carbon ecosystem on Lakkang Island, Makassar City reached around 58.29 Ha or 17% of the total area of 341.94 Ha or 3.41 Km^2 . The dominating land cover is in the form of waterbodies and ponds, which is in accordance with the environmental conditions of Lakkang Island which is located between the Tallo River and the Pappa River, so it is very supportive of cultivation activities in the form of ponds on Lakkang Island (Mas'ud et al., 2021)

The blue carbon ecosystem in the form of mangroves after field observations can be seen that there is a dominating type of vegetation, namely the Nipah (*Nypa fruticans*) type as shown in Figure 6 below.

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Figure 6. Mangrove Vegetations That Dominating Lakkang Island

Nipah (*Nypa Fruticans*) is one of the original habitats of the blue carbon mangrove ecosystem, which generally grows along the river flow with the influence of tides or often referred to as the estuary (Wijana et al., 2023). In this case, Lakkang Island is also located at the mouth of the Tallo River in Makassar City. Nipah can be found growing dominantly in a river estuary because this species is classified as an invasive species. This species can suppress the growth of other mangrove species, and its population can increase rapidly due to high seed productivity, supported by anthropogenic activities (Eddy & Basyuni, 2020).

Although Nipah mangroves dominate, other types of mangroves can be found on Lakkang Island, namely Rhizopora (*Rhizopora mucronata*). This is in line with the results of research by (Fahmi et al., 2021) which states that several types of mangroves can be identified in the Tallo River estuary including the Nipah type (*Nypa fruticans*), Rhizopora type (*Rhizopora mucronata* and *Rhizopora apiculata*), Avicennia or Apiapi type (*Avicennia marina*), and Sonneratia type (*Sonneratia caseolaris*).

The results of monitoring physical conditions in the form of the density level of the blue carbon mangrove ecosystem show that about 46% of the ecosystem consists of dense mangroves, with an area of 26.61 Ha. However, about 30% of the ecosystem consists of sparse mangroves and the remaining 26% consists of medium-density mangroves. These results were determined through NDVI analysis of Sentinel 2A imagery of the Lakkang Island area acquired in July 2023 by integrating remote sensing and GIS technologies. Monitoring the blue carbon mangrove ecosystem through NDVI analysis to identify the distribution of mangrove vegetation and analyse its density level is also one of the methods often used in observing the condition or structure of mangrove vegetation in Indonesia. This is as stated in the guidelines for monitoring the structure of Indonesian mangrove communities by (Dharmawan et al., 2020).

The density of the blue carbon mangrove ecosystem indicates that the ecosystem structure is still well maintained. This can be related to its ecological functions, especially in absorbing carbon emissions and providing habitat for several flora and fauna species. Monitoring results also show that mangroves with dense structures are mostly scattered along the main flow of the Tallo River. At the same time, sparse and medium mangrove structures tend to be scattered around the added bunds, although they are also in the main river flow. This is related to utilising mangroves deliberately planted around ponds by the community to conserve mangroves and pond areas through the concept of sylvofishery (Arfan et al., 2022).

The density of blue carbon ecosystems is also related to the ability to absorb carbon emissions. Where the higher the density of blue carbon ecosystems such as mangroves, it can indicate the larger number of mangroves in an area, and the higher the carbon stock it can store (Prasetya, 2022). Research by (Rahman et al., 2020) shows that the blue carbon mangrove ecosystem in the Tallo River estuary in Makassar City, including the Lakkang Island area, has the potential to absorb carbon dioxide (CO_2) emissions of 351.02 tons/ha. This can then be a 'breath of fresh air' in climate change mitigation efforts that can be carried out in Makassar City, one of Indonesia's metropolitan areas.

Therefore, monitoring the blue carbon ecosystem on Lakkang Island, Makassar City, must continue to be carried out as a form of sustainable ecosystem management. This research proves that the integration of remote sensing technology and geographic information systems can be one of the ways that can be used to provide data more efficiently, quickly, and accurately. This includes monitoring the blue carbon ecosystem. The data can also be a reference for planning or other directions in managing the blue carbon ecosystem on Lakkang Island, Makassar City.

CONCLUSION

Through this research, it can be concluded that the integration of remote sensing technology and geographic information systems can be carried out as a form of monitoring of the blue carbon ecosystem on Lakkang Island, Makassar City. This monitoring process can be done more efficiently, quickly, and accurately. The monitoring results show that the distribution of blue carbon ecosystems on Lakkang Island, Makassar City, tends to be on the main flow of the Tallo River. However, overall it appears to surround the island area.

Physical conditions in the form of blue carbon ecosystem density levels can also be known, where most of them consist of mangrove conditions with high-density levels. The results of this study can be used as reference data in planning or directing the management of blue carbon ecosystems around Lakkang Island, Makassar City, in a sustainable manner.

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